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**TREE REGENERATION IN SMALL FOREST PATCHES: INTERACTION  
OF BROWSING AND ABIOTIC FACTORS**

Final Report

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## ABSTRACT

To better understand the impacts of white-tailed deer (*Odocoileus virginianus*) browsing within the woodlot forests of the Goddard Space Flight Center (GSFC), the deer population size was monitored for three years, the forest vegetation was sampled to determine species composition and size structure, and an experimental study of browsing effects on seedling recruitment and survivorship was carried out. During 1994 to 1996, the deer population increased from approximately 50 to 69 individuals. Calculated from basal area, forest overstory composition of the GSFC woodlots is 55% virginia pine (*Pinus virginiana*), 36% oak (primarily chestnut oak - *Quercus prinus* and southern red oak - *Q. falcata*), and 6% sweetgum (*Liquidambar styraciflua*). The understory composition is more diverse with 27% virginia pine, 24% oaks, 13% blackgum (*Nyssa sylvatica*), 7% red maple (*Acer rubrum*), and 4% each of sweetgum and sassafras (*Sassafras albidum*). Forest size structure suggests that the smaller size classes of trees (2-5 cm dbh) are less common than would normally be expected.

Deer browsing has virtually eliminated the shrub layer in the GSFC woodlot forests. Thus the enclosure experiment focused on small seedling recruitment and survivorship. Results indicate that the white-tailed deer population is having little effect on overall seedling survivorship, and at most a sporadic impact on seedling recruitment. Annual seedling recruitment was similar for three years, although a significantly larger number of seedlings recruited into the closed (no browsing plots) early in the experiment. Survivorship varied annually, but no difference in rates of survivorship were apparent between the closed and open (browsed) plots. Deer damage to the shrub and understory layers of these woodlots is apparent. Thus we hypothesize that microenvironmental factors control seedling recruitment and survivorship, and deer browsing controls growth and death processes of seedlings as they enter the shrub layer.

## PUBLICATIONS CREDITING NASA GRANT NAG 5-2042

Seagle, S.W., and J.D. Close. 1996. Modeling white-tailed deer *Odocoileus virginianus* population control by contraception. *Biological Conservation* 76: 87-91.

Penland, K.I. (In Preparation) The effect of white-tailed deer browsing on tree seedling recruitment and survivorship in forest fragments. M.S. Thesis. University of Maryland at College Park.

## INTRODUCTION

Deer browsing effects on forest vegetation and individual tree species have been well documented (Bramble and Goddard 1953, Webb et al. 1956, Curtis and Rushmore 1958, Harlow and Downing 1970, Ross et al. 1970, Anderson and Loucks 1979, Alverson et al. 1988, Stewart and Burrows 1989, Storm et al. 1989, Tilghman 1989, Warren 1991, Anderson and Katz 1993) for many forest types in the United States. These studies have generally focused on decreased rates of forest understory regeneration and impacts on local populations of specific tree species. In regional or local areas of deer overabundance these impacts are important for maintaining tree species diversity and controlling forest understory physical structure, which may in turn influence habitat for other animal species.

Most experimental work with browsing impacts has focused on quantifying the loss of regeneration capacity by using exclosure plots and controls. These investigations reveal important parameters related to forest dynamics, but often fail to measure or consider the variety of other factors that influence tree seedling germination and establishment. For example, Alverson et al. (1988), based on experimental and observational studies, suggested that white-tailed deer (*Odocoileus virginianus*) were principally responsible for the regeneration failure of eastern hemlock (*Tsuga canadensis*) in the upper mid-west of the United States. Re-examination of this regeneration failure, from a more holistic perspective, indicated that deer browsing may be secondary to hemlock life history characteristics, forest ecosystem dynamics, disturbance regimes, land use patterns, and climatic variation in explaining wide-spread regeneration failure of hemlock (Mladenoff and Stearns 1993). Similarly, Seagle and Liang (1997) hypothesized that long-term regeneration patterns under browsing pressure from deer may be counter-intuitive to expected pattern simply because of the inertia of current vegetation. In particular, species life histories, tree species composition, and the age structure of a forest prior to the onset of intensive browsing may mask browsing impacts on trends in forest regeneration for substantial periods of time, depending on overstory and understory species longevity.

Forest tree regeneration is a complex interaction of seed production by overstory or understory trees, seed predation and dispersal (Sork 1983), soil characteristics necessary for germination (Burns and Honkala 1990), herbivory of seedlings that have germinated (Louda et al. 1990), and physical factors such as weather that influence resource availability to seedlings as well as seedling physiology. Further complicating these interactions is the temporal and spatial variability that accompanies many of these factors. Thus extrapolations that are made across time or space scales from local studies must be done with care. This is especially the case for management of natural resources that carry both cultural and economic value.

White-tailed deer have reached unprecedented population levels in many parts of the eastern United States (McCabe and McCabe 1984), including many suburban areas. While a valuable natural resource for game management, the detrimental impacts of browsing by overabundant deer are also well-documented (Anderson and Loucks 1979, Storm et al. 1989), as are the accident risks associated with deer overpopulation in urban and suburban settings (Decker and Connelly 1989). Sound

population management of white-tailed deer depends on understanding both the impacts and benefits associated with deer populations in such settings.

## OBJECTIVES AND COMPLETION STATUS

The objectives of this project focused on establishing baseline data for forest understory conditions, deer populations sizes, and effects of deer browsing on tree regeneration at NASA's Goddard Space Flight Center (GSFC) in Greenbelt, MD. Specific objectives were to:

1. *Estimate the deer population size at GSFC and project population change under a scenario of immunocontraception.* Population size was estimated by direct counts of deer, and the resultant number used to set initial conditions for a population model comparing alternative population management scenarios.
2. *Document changes in the deer population size at GSFC over the duration of the project, during which population reduction by female immunocontraception would be attempted by NASA personnel as an independent project.* Population size was monitored over the period of this study, although for multiple reasons population reduction efforts using immunocontraception were not attempted.
3. *Document current deer browsing impact on vegetation regeneration in small forest patches.* An experimental design of exclosures and control plots were used to evaluate this impact.
4. *Evaluate vegetation regeneration relative to deer population size over the course of the project.* Both regeneration rates and deer population sizes were characterized over the project's four year period.

## METHODS

### Study Site

The 170 ha Central Campus of NASA's Goddard Space Flight Center (GSFC) in Greenbelt, MD, was utilized for this work. The Central Campus is enclosed by 2.6 m chain link fence that retards but does not eliminate deer movement to and from the site. Land use within the Central Campus includes buildings, parking lots, lawns, and scattered woodlots. Approximately 30% of the Central Campus is comprised of 20 scattered woodlots, which range widely in size. The largest woodlots border the perimeter of the Central Campus, with those on the western (West woodlot) and northern (North woodlot) borders occupying over 50% of the woodlot area. Upland forests of this region in Maryland are generally mixed hardwood and pine. Soils at

GSFC are of the Christiana-Sunnyside-Beltsville association, which typically has a sandy-clay composition, is well-drained, and has a compacted subsoil (Metcalf and Eddy 1993).

### **Deer Population Estimation**

Three techniques were initially used to census the deer population at GSFC. These included (1) strip counts, where an individual walked transects through the woodlots, counted deer within 25 m of the transect line, and scaled the number observed up to total woodlot area; (2) vehicle counts, where deer were counted from a vehicle driven along a set route in late evening when deer were largely grazing on the GSFC lawns, and (3) drive counts, in which approximately 15 individuals moved through each woodlot to drive deer past other personnel stationed strategically to count all deer. Although involving greater effort and coordination, the drive counts gave great consistency of results, and was the only method used after 1993. Results from nine drive counts, spanning 12 March 1994 to 26 October 1996 are reported here. All counts were carried out on weekends to minimize deer moving through on-site traffic.

### **Vegetation Sampling And Analysis**

To document current woodlot vegetation of the GSFC and determine potential seed sources for understory recruitment both the overstory and understory was sampled in the two largest woodlots (West and North). Thirty 16 m radius circular plots were used to sample the overstory (trees  $\geq 20$  cm dbh). These plots were located along parallel transects that ran the length of the long axis of each woodlot. Transects were 50 m apart and plots were centered on the transects at 65 m intervals. At least 65 m was maintained as a buffer between plot perimeters and the woodlot edges. In each of these plots all overstory trees were identified to species and dbh measured. Within each overstory plot, a smaller radius (5.6 m) circular plot, centered on the same transect point, was established and all understory trees ( $\geq 2$  cm,  $< 20$  cm dbh) were also identified and measured.

Tree species frequencies, basal areas, and diversity indices (Shannon index) were calculated for overstory and understory using the PC-ORD software package. The Shannon index was then converted to Hill's  $N_1$  (Ludwig and Reynolds 1988) as a final measure of diversity.

### **Experimental Manipulation Of Deer Browsing**

Ten 3x6 m experimental plots were established in spring of 1993 in the West woodlot to examine the impact of deer browsing on seedling regeneration. Only the West woodlot was used for this experiment to minimize vegetation variation. The West woodlot was chosen because of its relatively level topography and its size. Specific plot locations were chosen to minimize variation in overstory composition (i.e., seed source), canopy closure, edge effects, and obvious past human

disturbance. Each plot was oriented north-south for standardization. Five plots were randomly chosen and assigned to be control plots (open). The remaining five plots were designated as treatment plots (closed). a 2.6 m high, mesh (4x3 cm) fence was erected around each closed plot. Each plot was gridded into 19 subplots to aid in orientation during seedling censuses.

In late August and September of 1993-1996, all seedlings in each plot were located, identified to species, and measured for height (cm) and basal diameter (mm, using Mitutoyo digital calipers). Each individual was tagged in the field using an aluminum tag loosely secured around its base. In addition each individual was mapped on plot maps. Raccoon damage to the aluminum tags led to subsequent use of only mapping to track each seedling. Thus complete censuses of seedlings occurred on each control and treatment plot for each year of this project to document annual recruitment and survivorship by species. Highly skewed data and, in some cases, small sample sizes dictated that a nonparametric ranked medians test be used for statistical analysis of treatment and year effects.

### **Weather Data**

Maximum daily temperature and total daily rainfall data were provided by the University of Maryland's State Climatology Office for January 1992 through September 1996. These data were collected at the Beltsville Agricultural Research Center which is approximately 8 km from GSFC. Total monthly rainfall and the monthly average of high temperatures are reported here.

## **RESULTS AND DISCUSSION**

### **Deer Population And GSFC Vegetation**

Based on the drive counts from 1994 to 1996, the deer population at GSFC increased from 47 to 69 individuals (Figure 1). This trend is marked by relative stability around 50 animals through July 1995, followed by a rapid increase. No specific reason for this apparent population increase was evident. Tilghman (1989) and Alverson et al. (1988) suggested that deer populations should be approximately 6.9 - 7.7 / km<sup>2</sup> and 8.0 - 9.3 / km<sup>2</sup>, respectively. These estimates were based largely on primary utilization of forest habitat. Using the entire area at GSFC, the deer population density was approximately 29 / km<sup>2</sup> before the population increase and 41 / km<sup>2</sup> in October 1996. Obviously these densities are high by comparison with Tilghman (1989) and Alverson et al. (1988); however, it is difficult to ascertain what the effects of grazing on lawns and copious supplemental feeding by some GSFC employees means to the deer population carrying capacity of the GSFC campus. In addition, deer are known to move between GSFC and surrounding properties. Whether these movements represent feeding forays or true losses/additions to the population is unknown. Without intensive studies that involve marking of individual deer for identification we cannot determine how immigration and emigration

influence the GSFC population. However, population simulations indicate that relatively little immigration would be needed to offset herd reduction efforts using immunocontraception (Seagle and Close 1996).

The woodlot overstory composition (Figure 2a) at GSFC is dominated by virginia pine (*Pinus virginiana*) and oak species (red oak - *Quercus falcata*, chestnut oak - *Q. prinus*). Sweetgum (*Liquidambar styraciflua*) is the only other overstory species with notable basal area. The understory is generally dominated by the primary overstory species (Figure 2b). However, significant basal area of black gum (*Nyssa sylvatica*), red maple (*Acer rubrum*), and sassafras (*Sassafras albidum*) make the understory more diverse. Appendix A presents a complete list of species found in the field. Combined overstory and understory tree density was examined by size class to approximate the age distribution of woodlot trees (Figure 3). Although the two smallest size classes have high densities relative to larger size classes, we suggest that deer browsing has limited recruitment of individuals into the smallest size class (2-5 cm), resulting in a density slightly less than the next largest class (5-10 cm). This result confirms our visual impression that woodlots at GSFC have a depleted understory physical structure. Given the deer population size at GSFC and the impact on the 2-5 cm tree size class, it is probable that browsing has suppressed understory vegetation in these woodlots for five or more years.

### Seedling Regeneration

Despite random assignment of treatments (closed vs. open) to the experimental plots, the closed plot had a larger number of individual stems at the first census following the establishment of the experiment in 1993 (Figure 4). This difference increased significantly ( $P = 0.007$ ) in 1994 as a large number of seedlings became established in the closed plot. Gradual establishment of seedlings in the open plots and a slight decrease in seedlings in the closed plots narrowed this difference in 1995 and 1996 (Figure 4). The closed and open plot seedling numbers remained significantly different in 1995 ( $P = 0.01$ ), but were not significantly different in 1996. For the open and closed plots, respectively, seedling diversity by year was: 1993 - 2.55, 1.81; 1994 - 2.63, 2.61; 1995 - 1.81, 1.94; and 1996 - 2.91, 3.2. Thus from 1993 through 1996 both open and closed plots showed an overall increase in seedling diversity, with each treatment also having a small decline in 1993. Because both treatments have the same trend, we cannot attribute the increase in seedling diversity for the closed plots to lack of browsing, even though the closed plots did have a greater absolute change in diversity during the experiment. As an alternative explanation, the relatively small differences in seedling diversity between treatments suggest that deer browsing does not impact the tree species differentially, possibly because the high deer population density has resulted in a shortage of browse and decreased selectivity among browse species.

The number of tree seedlings in either closed or open plots reflects a balance between recruitment and survivorship. Recruitment was significantly higher ( $P = 0.001$ ) in the closed plots than open plots in 1994 (Figure 5). This difference resulted from a pulse of recruitment into the closed plots. No significant difference in recruitment between closed and open plots occurring in either 1995 or 1996 (Figure 5). At the species level, recruitment into the closed plots during 1994 was

dominated by significant ( $P < 0.05$ ) increases in the numbers of virginia pine (32% of all recruits), red maple (20% of all recruits), and blackgum (Figure 6). Recruitment into the open plots in 1994 was the lowest of any treatment or year (Figure 5), with no species representing the majority of individuals recruited (Figure 6). Recruitment was moderate for both open and closed plots in 1995. The open plot recruitment in 1995 came from sweetgum ( $P < 0.05$ ) and red maple seedlings, while the closed plot recruitment was largely sweetgum (Figure 6). Recruitment in 1996 was again moderate (Figure 5). Both open and closed plot recruitment was largely virginia pine (Figure 6) in 1996. Several aspects of seedling recruitment seem apparent. First, although a relatively large pulse of seedlings was recruited into the closed plots during the first year of the experiment, this recruitment rate for the closed plots was not sustained over successive years. However, total recruitment for both treatments was very similar from year to year. Second, the difference in recruitment rates between treatments was significant only in 1994. Third, different species dominate the recruitment class in different years. Fourth, recruitment by individual species varies through time, with only a few species contributing the most individuals to new recruits. Of the dominant overstory species, virginia pine contributed the most individuals to new recruitment for two of three years; chestnut oak contributed little. Sweetgum, common in both the overstory and understory had a single strong recruitment year in 1995. Other than sweetgum, red maple was the only understory species to have significant recruitment during this study. Finally, all of the species that made important contributions to recruitment (except blackgum) have small, wind-dispersed seeds.

Survivorship between years was initially calculated for all species and individuals combined, with the data stratified by treatment and length of the time interval (yrs) over which survivorship was calculated (Table 1). Within combinations of time intervals and treatments, notable variation existed for different years (Table 1). However, by simply averaging the observations within each combination of time interval and treatment we found that very little variation existed between the closed and open treatments (Table 1). These results indicate that survivorship is not a function of deer browsing for these plots. As expected, the probability of a seedling surviving decreases through time (Table 1). Because the specific year cohort of seedlings in the first (1993) plot census was not known, cohort survivorship could be calculated only for 1994 and 1995 (Table 2). The 1994 closed plot cohort collectively displayed lower survivorship than the open plot cohort for both 1995 and 1996. This result is counterintuitive if deer browsing has an influence on survivorship. However, the differences in survivorship between the treatments were not significant for either 1995 or 1996. The 1995 cohort showed an opposite pattern, with survivorship into 1996 greater for the closed plots (Table 2). This difference was also not significant. Collectively, these analyses indicate that deer browsing has little effect on survivorship of small seedlings. Nonetheless, there is a high seedling mortality rate.

In examining the precipitation and temperature records for 1992-1996, we found that the growing seasons (May through September) of the three years for which we have survival data were distinctly different (Figure 7). The 1994 growing season lacked extremes in precipitation and had slightly above average temperatures, the 1995 season was one of drought, and the 1996 growing season was wet and cool. Overall recruitment, being relatively equal among these three years, appears



unaffected by the extreme weather conditions. However, GSFC is near the northern range boundary for sweetgum (Burns and Honkala 1990) and warmer, drier weather in 1995 may help explain increased sweetgum recruitment that year.

## CONCLUSIONS

The experimental portion of this project addressed the recruitment and survival of tree seedlings both with and without the presence of deer. In the temporal scope of this study, white-tailed deer browsing does not appear to influence the short-term (one to three years) survivorship of small seedlings at GSFC. This does not indicate that deer browsing has no influence on regeneration in the GSFC woodlots. The extreme lack of understory, prevalence of browsed twigs, and low number of trees in small size classes attest to the impact of deer on the structure of the forest. Rather, we propose sequential controls on regeneration, whereby germination and establishment is controlled largely by microenvironment, and deer browsing exerts impacts on seedlings once they are established and growing into the shrub layer of the forest. Further tests of this hypothesis will require new experimental designs because the current status of the GSFC woodlot understory is so degraded that suitable sample sizes of shrub-level trees do not exist.

Seedling recruitment results from the temporal and spatial juncture of appropriate abiotic and biotic conditions. These conditions minimally include seed availability, a suitable physical microenvironment for germination and establishment, and escape from seed predation and seedling browsing. The first two of these three conditions were apparently met during each year of our experiment because a rather consistent number of seedlings (75, 75, and 83 during years one through three, respectively) was recruited each year. Our experiment was directed toward testing the impact of the third condition - seed predation and seedling browsing by white-tailed deer. Superficially, our results indicate that in 1994 the exclusion of white-tailed deer from experimental plots significantly increased recruitment rates. Through time, however, this result is inconsistent because closed and open plot recruitment rates were essentially equal in 1995 and 1996. We found no obvious biases in our field design (e.g. seed tree locations in relation to closed and open plots), and suggest that the temporal sequence of recruitment more likely reflects chance events in 1994. This interpretation is also consistent with our survivorship data which indicates no impact of browsing on seedling survival. We have noted that most of the tree species regenerating in our experimental plots have small, wind dispersed seeds. In contrast, chestnut oak is a canopy dominant whose contribution to seedling recruitment was relatively small - over three years only 13 individuals were recruited into both treatments combined. However, 11 of those recruits were found in closed plots. The effect of deer on seedling recruitment may thus be through seed predation of those heavy seeded mast species that are heavily favored by deer rather than browsing germinated plants of species whose seeds are generally not physically accessible by deer.

## ACKNOWLEDGMENTS

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Table 1. Proportion of all individual seedlings surviving for either one, two, or three years. Data are grouped by treatment.

TREATMENT	PROPORTION SURVIVING					
	TIME (YRS):		1		2	
	YEARS:		93-94	94-95	93-95	94-96
CLOSED			.77	.54	.57	.51
OPEN			.65	.62	.50	.38
CLOSED (Averaged within TIME)				.63		.40
OPEN (Averaged within TIME)				.59		.40

Table 2. Survivorship for 1994 and 1995 seedling cohorts in the open and closed treatments.

COHORT	TREATMENT	PERCENT SURVIVAL	
		1995	1996
1994	OPEN	67	40
	CLOSED	45	23
1995	OPEN		38
	CLOSED		63

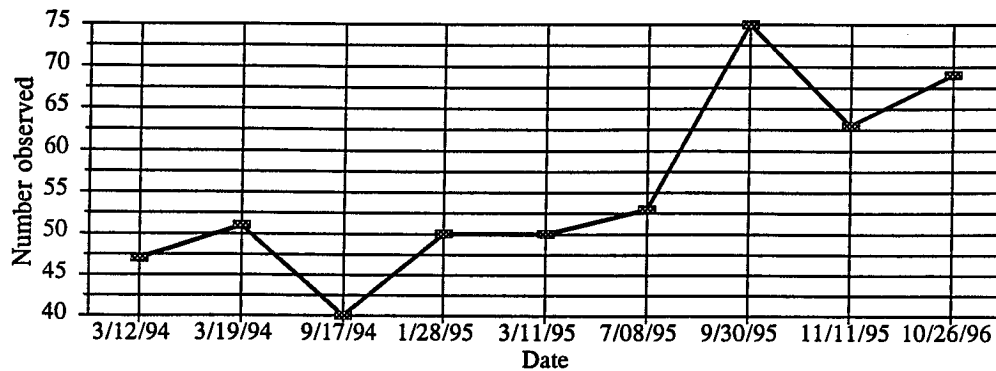


Figure 1. Total number of deer observed for nine sampling periods from March 1994 through October 1996 on the Goddard Space Flight Center, Greenbelt, MD.

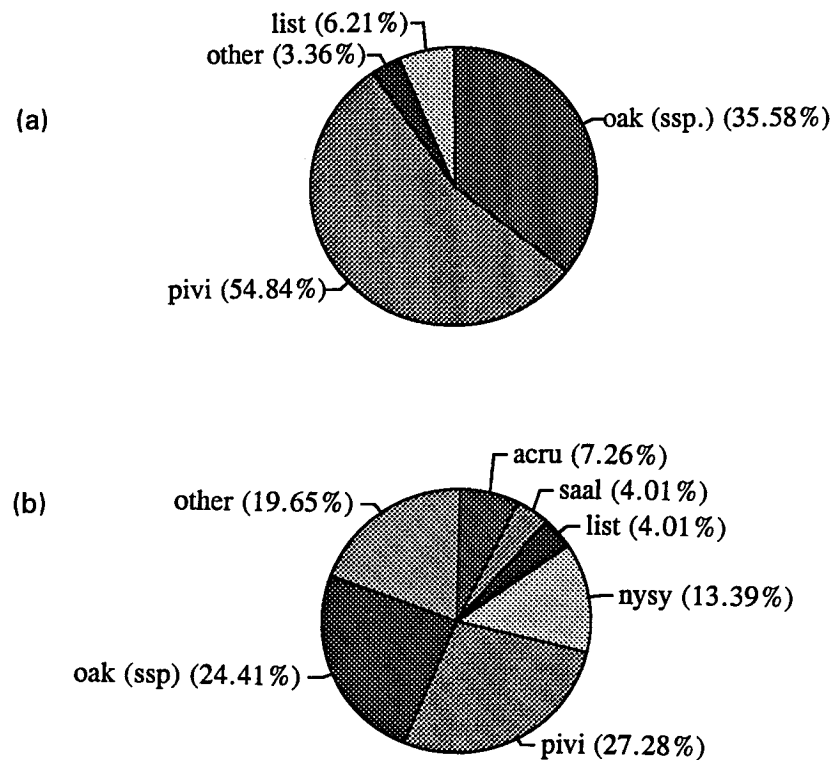


Figure 2. Forest overstory (a) and understory (b) composition of the North and West woodlots on the Goddard Space Flight Center, MD. Percentages were calculated from basal area for each species. Tree species are: oak species - southern red oak and chestnut oak; pivi - virginia pine; nysy - blackgum; list - sweetgum; acru - red maple; saal - sassafras.

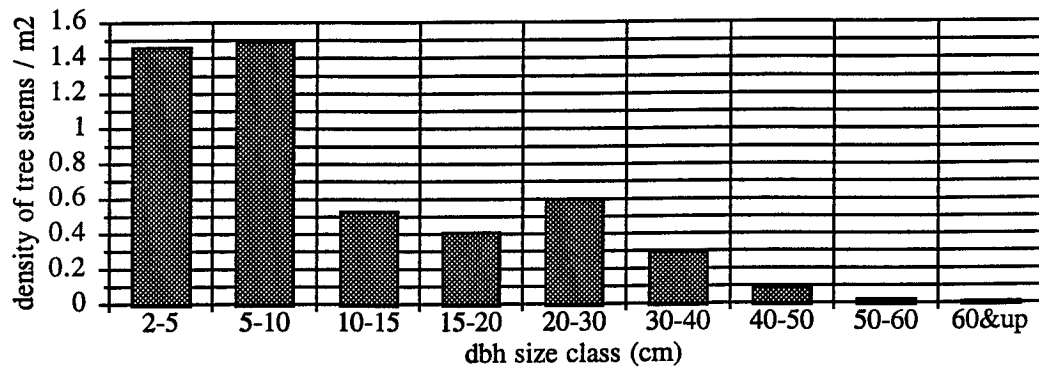


Figure 3. Density of combined overstory and understory tree stems grouped by diameter at breast height (dbh) size intervals. Tree were sampled in the North and West woodlots at Goddard Space Flight Center.

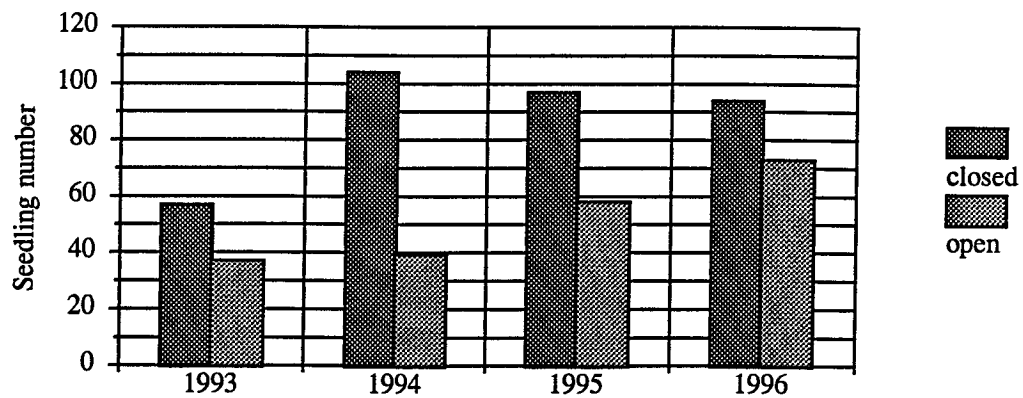


Figure 4. Total number of individual tree seedlings (all species combined) found in the closed (exclosure) and open (control) experimental plots from 1993 through 1996.

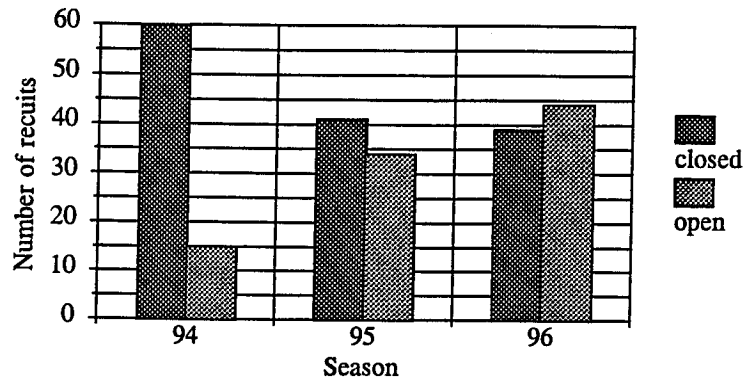


Figure 5. Recruitment of individual tree seedlings into the closed and open experimental plots during 1994 through 1996.

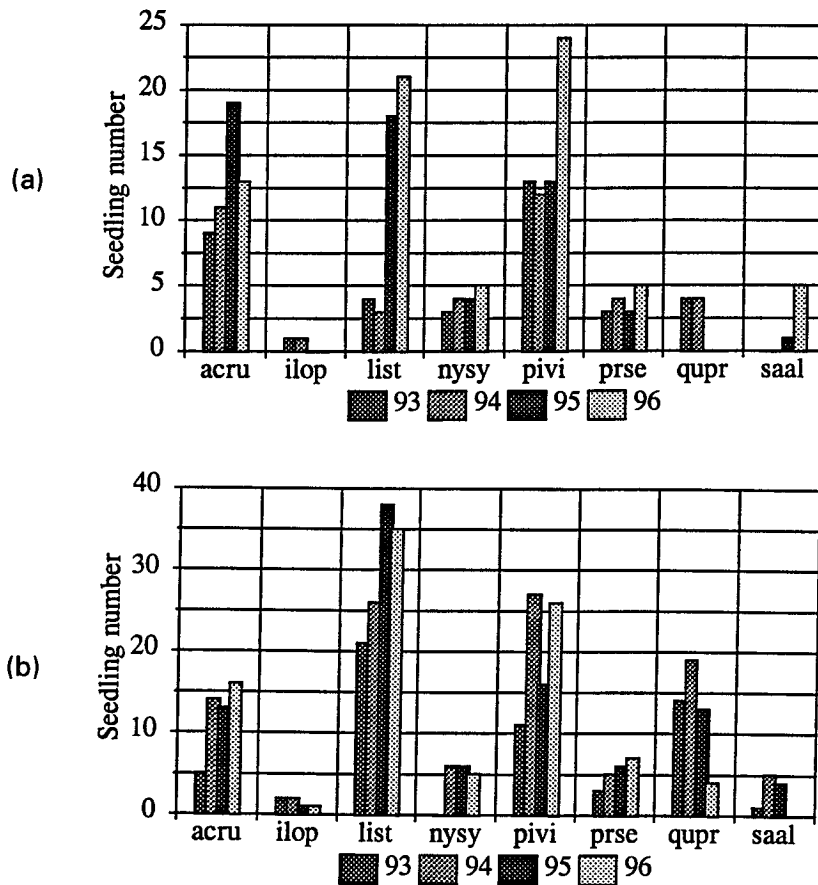


Figure 6. Number of individual seedlings found in the open (a) and closed (b) experimental plots for each of the eight major tree species during years 1993 through 1996. Species codes are: acru - red maple, ilop - American holly, list - sweetgum, nysy - blackgum, pivi - virginia pine, prse - black cherry, qupr - chestnut oak, saal - sassafras.

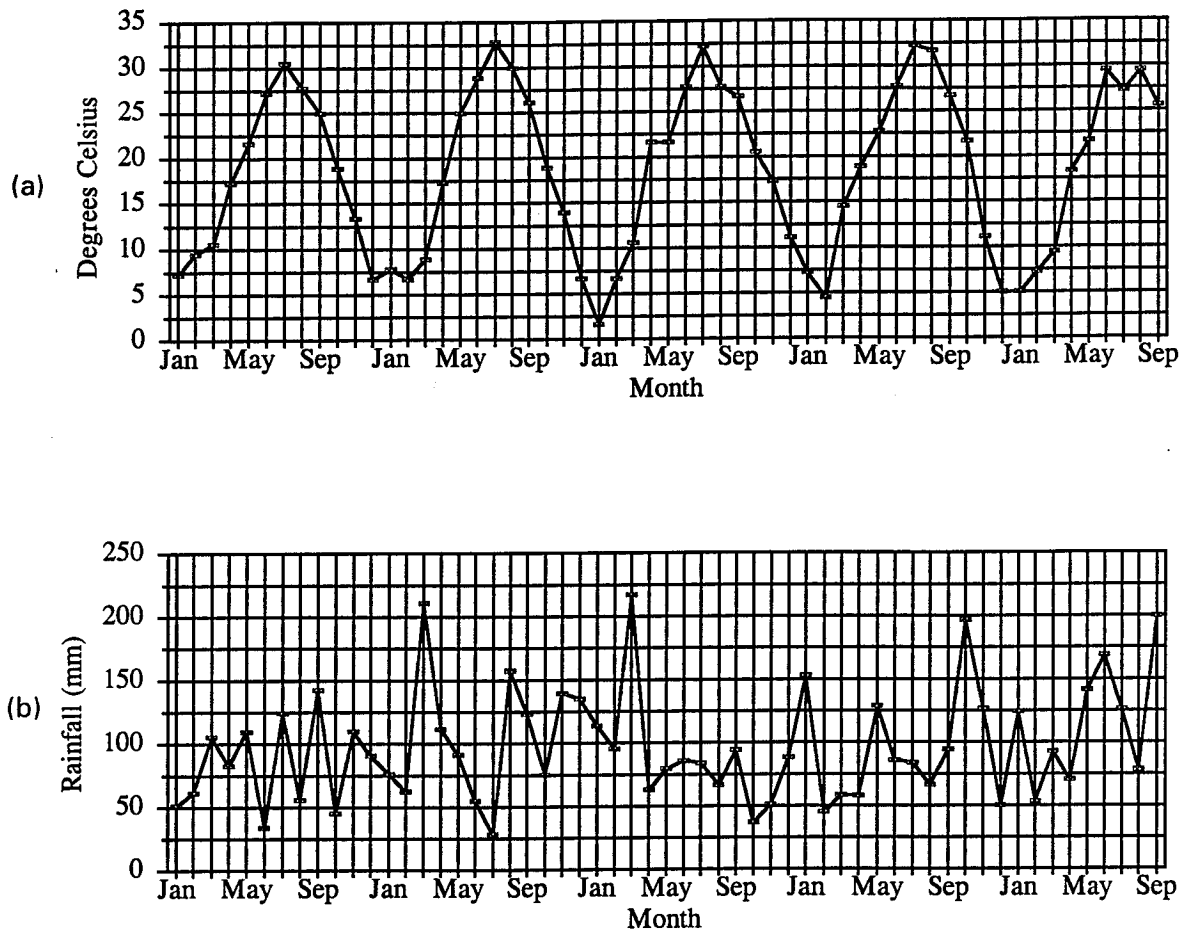


Figure 7. Time traces of daily maximum temperature averaged by month (a) and total monthly precipitation (b) for 1992 through 1996. Data were collected at the Beltsville Agricultural Research Center, approximately 8 km from Goddard Space Flight Center.



## APPENDIX A

Listing of all tree and shrub species found in the vegetation analysis of Goddard Space Flight Center. Information provided includes the genus, species, family, common name, and abbreviation used in this report.

Abbreviation	Genus and species	Common name	Family
<i>acru</i>	<i>Acer rubrum</i>	red maple	Aceraceae
<i>amar</i>	<i>Amelanchier arborea</i>	downy service berry	Rosaceae
<i>cagl</i>	<i>Carya glabra</i>	hickory (pignut)	Juglandaceae
<i>cato</i>	<i>Carya tomentosa</i>	hickory (mockernut)	Juglandaceae
<i>capu</i>	<i>Castanea pumila</i>	allegheny chinkapin	Fagaceae
<i>crbo</i>	<i>Crataegus boyntoni</i>	boynton hawthorn	Rosaceae
<i>ilop</i>	<i>Illex opaca</i>	american holly	Aquifoliaceae
<i>kala</i>	<i>Kalmia latifolia</i>	mountain laurel	Ericaceae
<i>list</i>	<i>Liquidambar styraciflua</i>	sweetgum	Hamamelidaceae
<i>litu</i>	<i>Liriodendron tulipifera</i>	tulip poplar	Magnoliaceae
<i>nysy</i>	<i>Nyssa sylvatica</i>	black gum	Cornaceae
<i>pivi</i>	<i>Pinus virginiana</i>	Virginia pine	Pinaceae
<i>pita</i>	<i>Pinus taeda</i>	loblolly pine	Pinaceae
<i>prse</i>	<i>Prunus serotina</i>	black cherry	Rosaceae
<i>qual</i>	<i>Quercus alba</i>	white oak	Fagaceae
<i>quco</i>	<i>Quercus coccinea</i>	scarlet oak	Fagaceae
<i>qufa</i>	<i>Quercus falcata</i>	red oak (southern)	Fagaceae
<i>quph</i>	<i>Quercus phellos</i>	willow oak	Fagaceae
<i>qupr</i>	<i>Quercus prinus</i>	chestnut oak	Fagaceae
<i>quru</i>	<i>Quercus rubra</i>	red oak (northern)	Fagaceae
<i>qust</i>	<i>Quercus stellata</i>	post oak	Fagaceae
<i>quve</i>	<i>Quercus velutina</i>	black oak	Fagaceae
<i>saal</i>	<i>Sassafras albidum</i>	sassafras	Lauraceae
<b>Non-tree species</b>			
	<i>Smilax glauca</i>	white and round leaf	
<i>smlx</i>	<i>Smilax rotundiflora</i>	greenbriars	Liliaceae
<i>vaco</i>	<i>Vaccinium corymbosum</i>	highbush blueberry	Ericaceae